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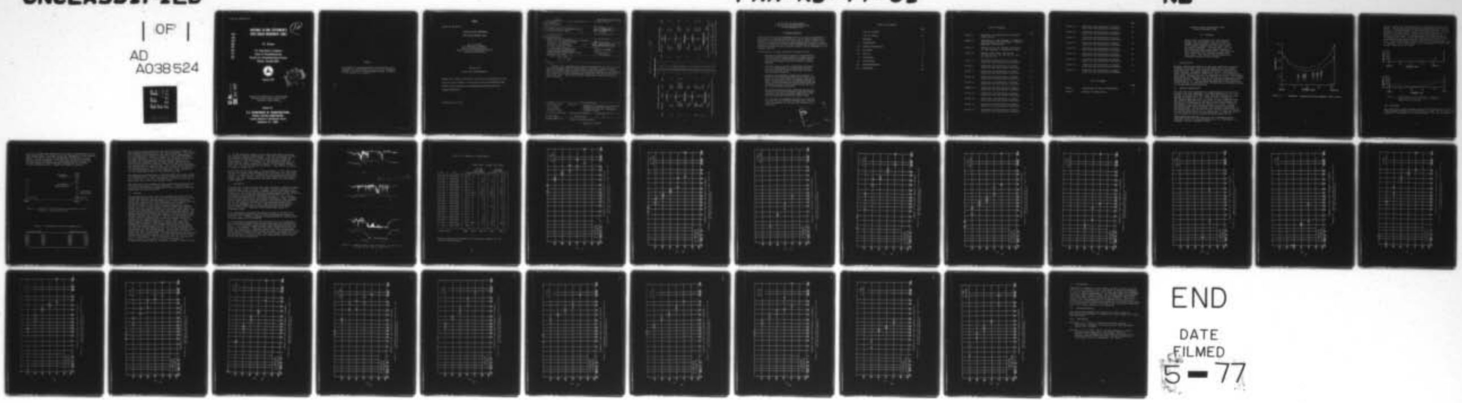

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Report No. FAA-RD-77-51

ANTENNA TILTING EXPERIMENTS OVER RADAR MICROWAVE LINKS

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W.J. Hartman

U.S. Department of Commerce
Office of Telecommunications
Institute for Telecommunication Sciences
Boulder, Colorado 80302

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

January 1977

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Washington, D.C. 20590

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ANTENNA TILTING EXPERIMENTS

OVER RADAR MICROWAVE LINKS

By W.J. Hartman
U.S. Department of Commerce
Office of Telecommunications
Institute for Telecommunication Sciences
Boulder, Colorado 80302

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16. Abstract

Signal level recordings were made simultaneously for two systems, one utilizing an antenna tilted upward to obtain a 2 dB loss over optimum alignment and the other using an untilted antenna. The path was a 42.3 km FAA radar microwave link between Yemassee, South Carolina and Hardeeville, South Carolina over relatively flat terrain covered with tall trees. The results showed essentially identical fading on both systems.

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METRIC CONVERSION FACTORS

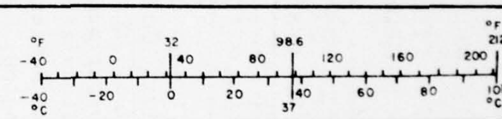
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

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The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource — the electromagnetic radio frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

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ANTENNA TILTING EXPERIMENTS OVER RADAR MICROWAVE LINKS

W.J. Hartman*

Signal level recordings were made simultaneously for two systems, one utilizing an antenna tilted upward to obtain a 2 dB loss over optimum alignment and the other using an untilted antenna. The path was a 42.3 km FAA radar microwave link between Yemassee, South Carolina and Hardeeville, South Carolina over relatively flat terrain covered with tall trees. The results showed essentially identical fading on both systems.

I. INTRODUCTION

Antenna tilting experiments of the type previously reported (Hartman and Smith, 1975) were performed over a FAA Radar Microwave Link (RML) path between Yemassee and Hardeeville, South Carolina, hereafter referred to as YH. The previous tests (Hartman and Smith, 1975) were over a path between Boone and Fowler, Colorado and will be referred to as BF. Significant improvement was obtained over the BF path by tilting the antennas slightly upward. However, the same techniques resulted in no improvement at YH. The probable explanation of the difference in the results is presented here in terms of the different types of terrain along the two paths.

II. TERRAIN DESCRIPTION

The path for this experiment is approximately 42.3 km long, running from near Yemassee, SC to near Hardeeville, SC. The terrain is essentially flat, with sections covered by trees ranging in height to 35 m. There is a 76.2 m tower at the Yemassee end and a 109.7 m tower at the Hardeeville end. The normal communications utilize fly swatter antennas consisting of a reflector on the tower with a dish located on the ground or on the building serving as a feed. Figure 1 illustrates these path features with greatly exaggerated vertical scale. In this figure, two reflectors are shown at the Hardeeville end at 106.7 m and at 81.7 m, and the location of the two dishes used for the experiment is shown at 76.2 m. The ray shown is for an effective earth radius of 2/3.

*The author is with the Institute for Telecommunication Sciences, Office of Telecommunications, U.S. Department of Commerce, Bouler, Colorado 80302.

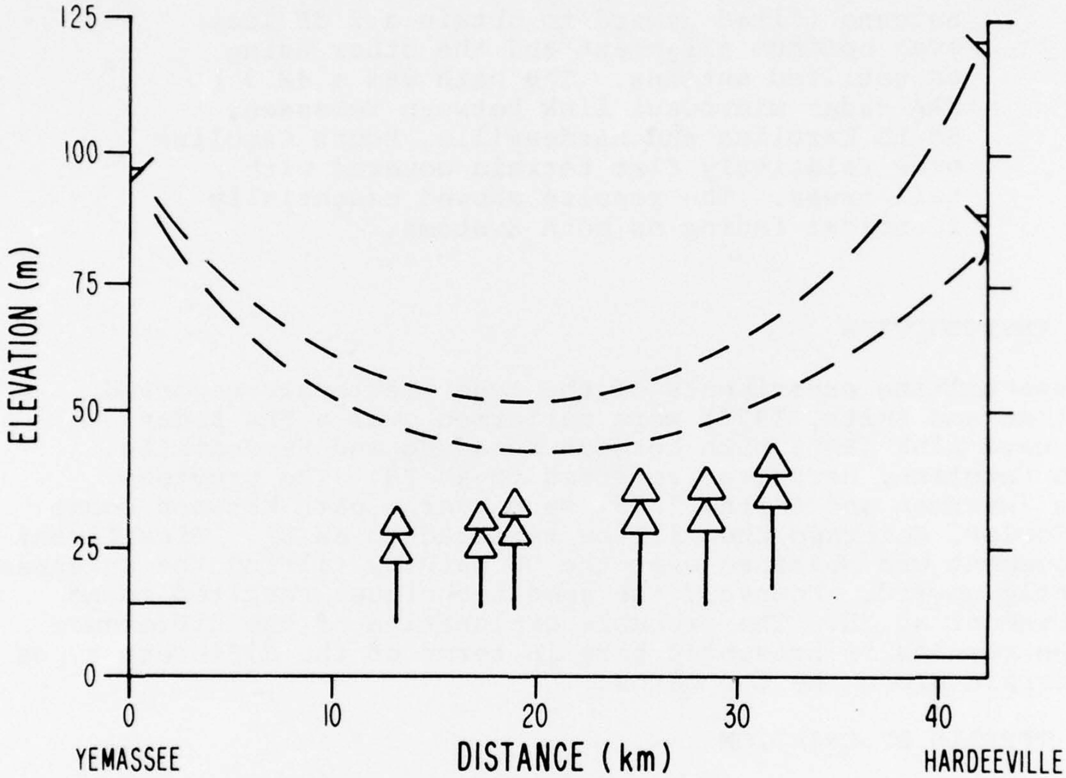


Figure 1. **Yemassee - Hardeeville path geometry (flat earth).**

Figure 2 shows the YH path and the BF path drawn to the same scale. The dashed lines indicate the geometric path with no bending. The differences in the terrain are obvious: The BF terrain is higher at both ends than at the center of the path while the YH path shows a slight rise toward the center because of the trees. In keeping with the rationale given in Hartman and Smith (1975), the antenna tilting should give protection during fading periods over paths of the BF type (i.e., bowl-like terrain) while slight if any improvement would be expected for YH type paths (i.e., flat paths, or paths with slight rises along the path).

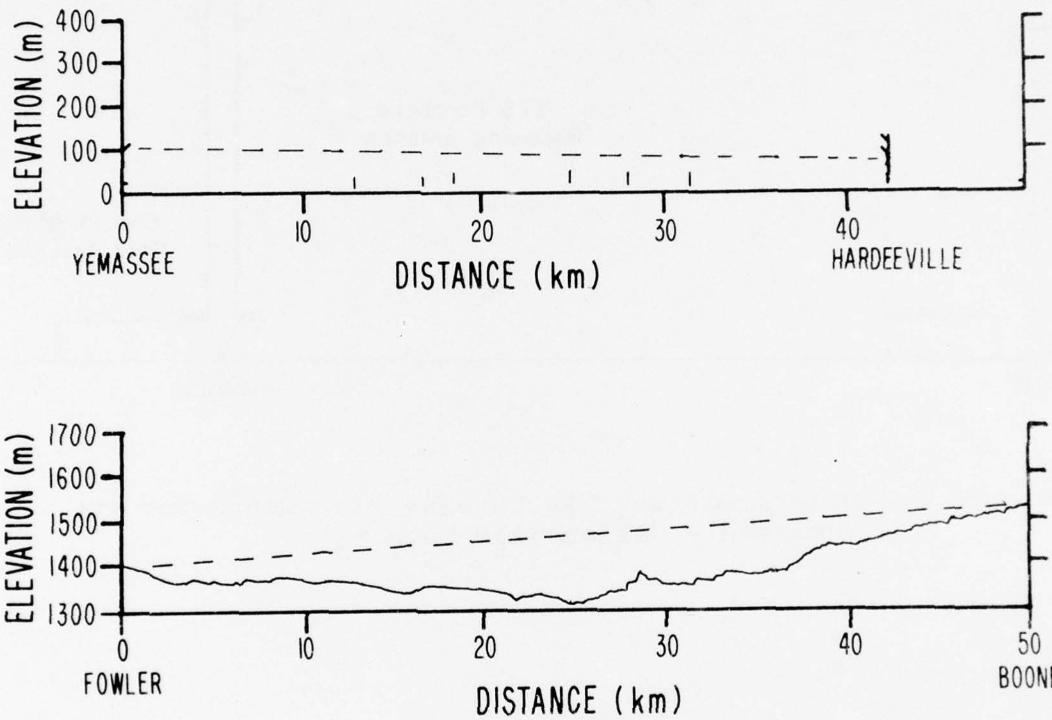


Figure 2. Comparison of the Yemassee - Hardeeville path geometry with the Boone - Fowler geometry (flat earth).

III. EQUIPMENT

The operational paths between Yemassee and Hardeeville use periscope antenna systems with reflectors on towers fed by dishes near the base of the tower or on the buildings. For the experiment,

two 1.2 m dishes were mounted on the tower at Hardeeville at the same height below the lower of the two reflectors on the Yemassee side of the tower. The two dishes were separated by 1.75 m. Figure 3 shows a diagram of the location of the FAA antennas. Because of the diversity, both space and frequency, over the YH path numerous frequencies were transmitted or received at the Hardeeville site. These are listed in table 1.

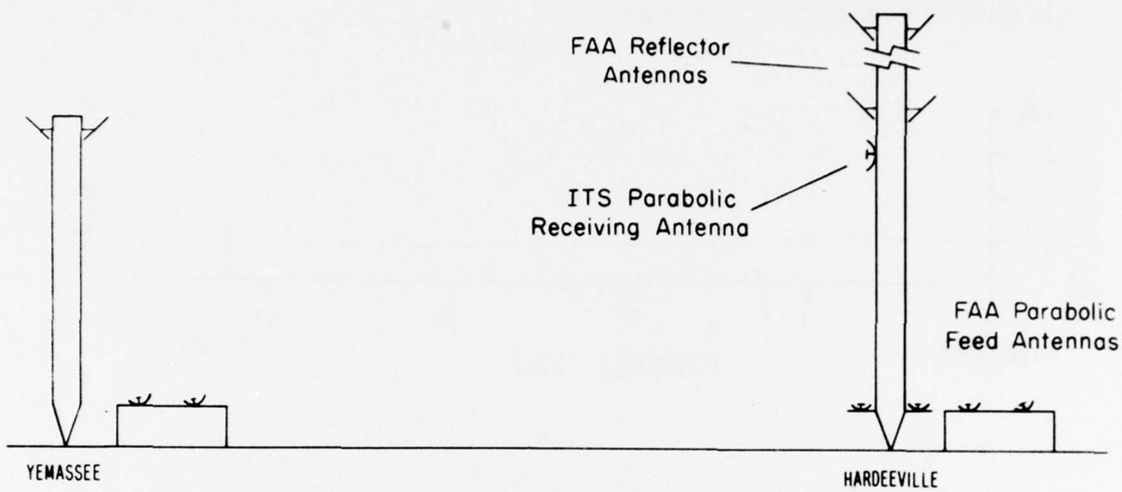


Figure 3. Diagram of the FAA antenna placements for the Yemassee - Hardeeville path.

Table 1. Frequencies in use at Hardeeville.

Received (MHz)		Transmitted (MHz)	
8330	7560	8290	7605
8210	7430	8170	7515
8045	7340	8085	7475
7925	7250	7965	7385
7805	7205	7845	7295
7685	7160	7725	7205

Two receivers were mounted on the tower directly behind the dish antennas which were used for the experiments. The results were limited by interference from some of the frequencies in use at Hardeeville (table 1) because of the broad bandwidth of these receivers. In particular, the frequency at 7160 MHz was used for the experiment and the nominal signal level received from Yemassee during steady signal conditions was -43 dBm and -45 dBm for the two receivers using the untilted and tilted antennas respectively. The signal being transmitted from Hardeeville at 7205 MHz produced a level of -75 dBm and -77 dBm respectively at the two receivers. This limitation will be discussed further in the results section.

The receivers incorporated log-IF-amplifiers which were linear in voltage within 1 dB over a range of received signal levels from -20 dBm to -100 dBm. The output voltage was recorded on both paper chart rolls and magnetic tape.

The receivers were arranged so that calibration could be done from the ground using a signal generator. A stable local oscillator and the broad bandwidth of the receivers prevented fading due to frequency drift.

IV. RESULTS

The measurements covered the time between 2-8-76 and 3-9-76. During this period, the fading of the received signals on the tilted and untilted systems appears to be identical after taking into account the 2 dB difference in the systems and the different values of the limiting interfering signal. Figure 4(a)(b)(c) shows three different periods of fading. Figure 4(a) and (b) are typical of the fading that occurred during the hours between sunset and sunrise, while figure 4(c) is the only occurrence of the very deep long-term fading. No fading was observed between the hours of 0800 and 1800 (local daylight savings time) and some fading was observed every day (night) between 1800 and 0800. For most of the nights, the signal either remained above -60 dBm or dropped below for periods of very short duration (<1 s per hour). A total of eight nights produced significant fading, and these are summarized in table 2. The columns for signals less than -75 dBm are biased because of the interference as explained earlier and are included primarily to give an indication of the behavior of the tilted system. The columns labeled signal level less than -70 dBm generally indicate the 2 dB lower signal for the tilted system. The few cases where the untilted system shows more time below the level than the tilted system are not significant. The distributions for the time periods given in table 2 are shown in figures 5 through 23. It should be noted that the triangles plotted in these figures

at -75 dBm generally appear on the right hand edge indicating the adjacent channel interference. For the two periods of very deep fading on February 13 (figs. 11 and 12) the signal did fall below -75 dBm indicating that the received signal was significantly lower. In figure 11, the occurrence of only one point for the tilted system is a result of the signal being less than -70 dBm for the entire period. This period of fading is shown in figure 4(c).

During the period from March 1 through March 9, 1976, the tilted antenna was tilted down instead of up to achieve 2 dB loss over optimum. Figures 22 and 23 shown the only data with significant fading from this period. This and other data from this period support the same conclusions as the data taken with the antenna tilted upward.

V. DISCUSSION

Although the YH signal level data were limited by adjacent channel interference, fades of 25 dB, as great as those recorded at BF, could be (and were) recorded. Further, within this range the YH signals for the tilted and untilted systems appear nearly identical in contrast to the signal differences observed at BF. Two plausible explanations for this behavior are (1) the YH fading was primarily diffraction type fading (Dougherty, 1968) in which case no improvement could be expected from tilting the antennas and (2) the angular separation of the multipath components and direct component is so small that discrimination against the multipath components is not possible with the antennas used in the tests. Probably both explanations apply at different times.

It is tempting to classify the fading records of figure 4 as classical diffraction fading for 4(c) and multipath fading for 4(a) and 4(b). However, similar classifications of records from BF can be shown to be erroneous.

No meteorological parameters were measured for this experiment, but qualitative weather observations were noted by personnel on site. No correlation exists between these observations and the fading. For example, light fog was noted during the fading displayed in figure 4(c). However, there were other nights when light fog was present and no fading occurred. The weather for the period shown in figure 4(b) was clear with brisk winds, and, for the period shown in figure 4(a), the observations showed light winds with early morning fog.

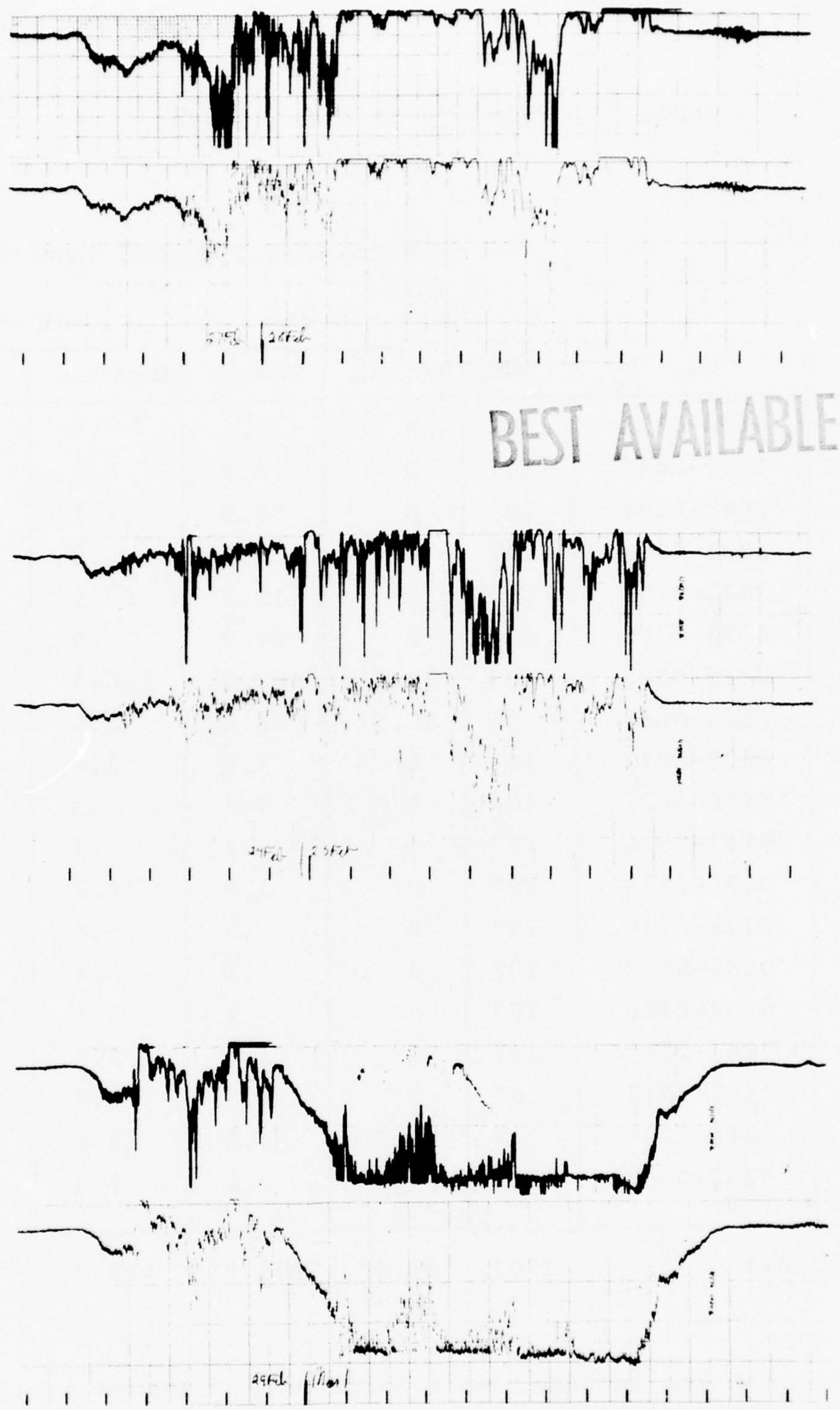


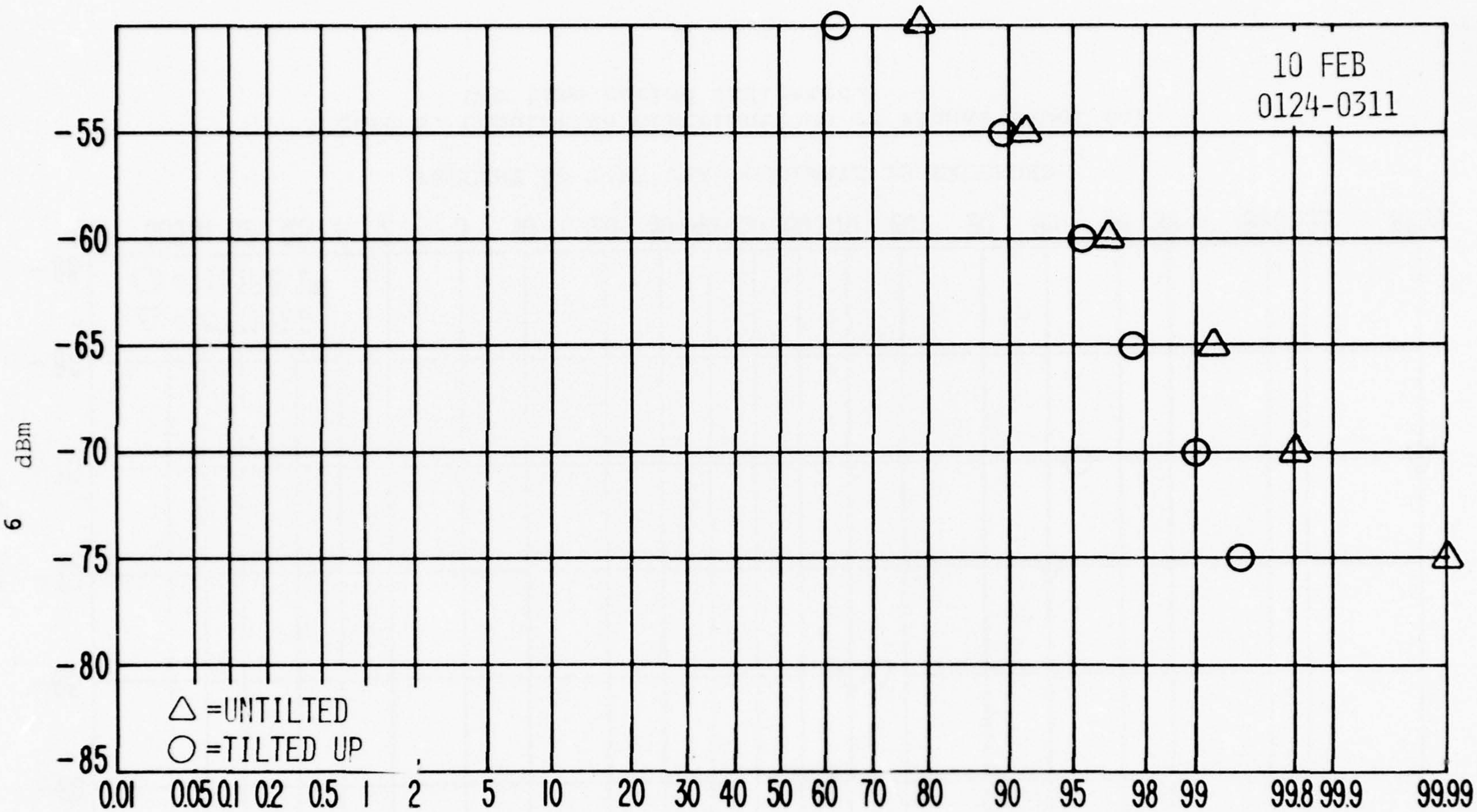
Figure 4. Sample signal level recordings (a) Feb 27, 28, (b) Feb 24, 25, and (c) Feb 12, 13.

Table II. Summary of fading data.

Date	Time	Min_T	-75 dBm Untilted	-75 dBm Tilted	-70 dBm Untilted	-70 dBm Tilted
10 Feb	0124-0311	107	0	.4	.1	1.1
12 Feb	1900-2047	107	0	2.8	5.3	18.8
12 Feb	2047-2234	107	0	56.3	77.1	90.4
12 Feb	2234-0021	107	0	.2	.8	1.1
13 Feb	0021-0208	107	0	11.3	17.5	33.9
13 Feb	0208-0355	107	0	64.9	79.9	100.5
13 Feb	0355-0542	107	24.4	103.0	106.9	107.0
13 Feb	0542-0636	54	35.3	51.8	52.8	52.7
20 Feb	0100-0247	107	0	1.0	1.8	2.1
20 Feb	0434-0621	107	0	3.1	3.3	5.9
23 Feb	0147-0334	107	0	.4	.3	1.1
23 Feb	0334-0521	107	0	1.8	12.9	12.4
25 Feb	0159-0346	107	0	.2	.4	1.6
25 Feb	0346-0533	107	0	.4	1.4	3.5
25 Feb	0533-0720	107	0	.1	1.6	2.9
27 Feb	2200-2347	107	0	1.0	2.7	4.5
28 Feb	0500-0647	107	0	2.9	3.8	5.3
9 Mar	0045-0232	107	26.7	33.5	45.4	48.6
9 Mar	0232-0300	28	0	.4	5.3	5.8
TOTAL (min.)		1901	86.4*	335.5*	419.3	499.2

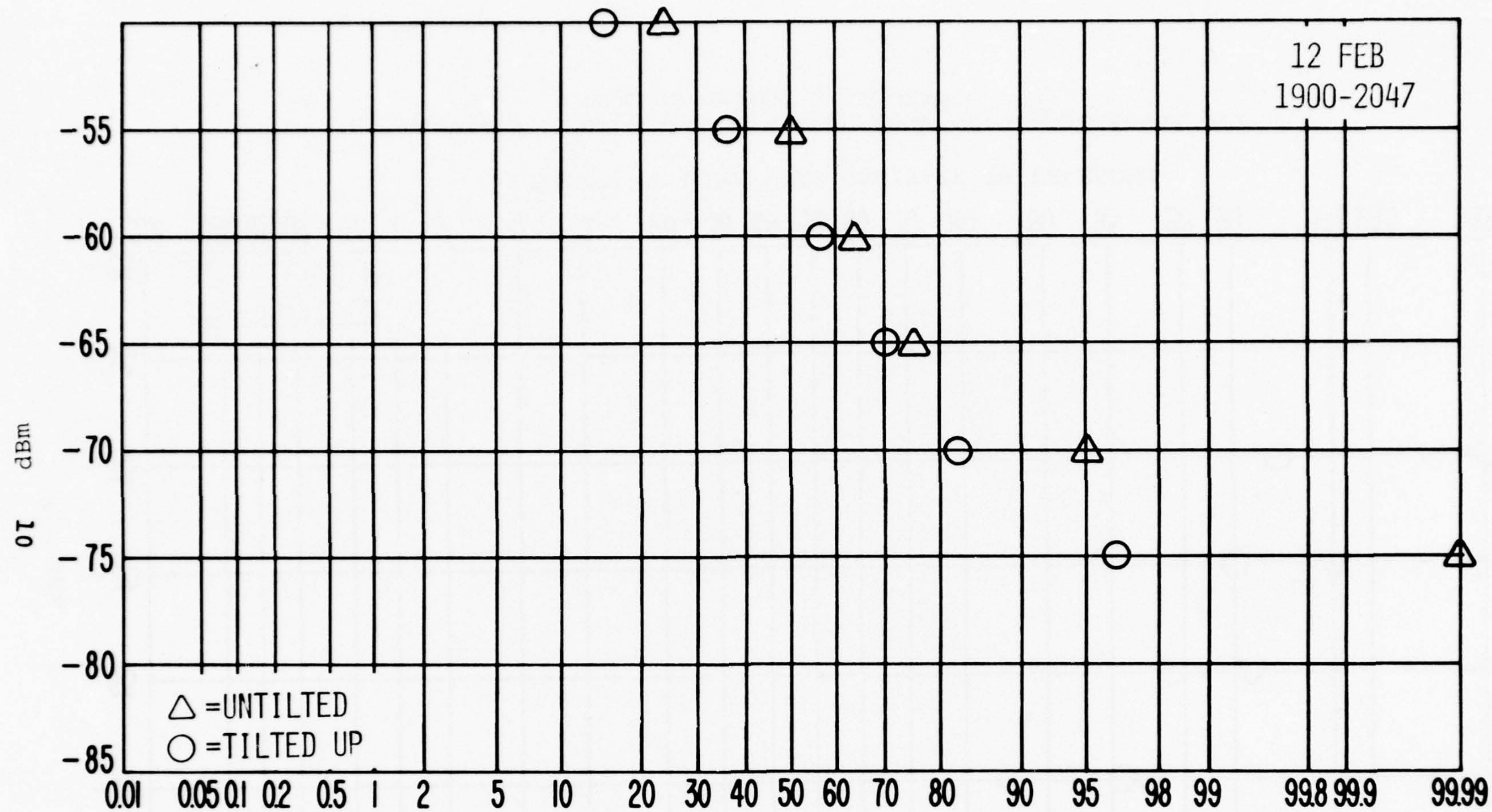
Time (min.) Signal Less Than (applies to the -75 dBm and -70 dBm columns)

*These columns are included as a guide only, because of the limiting interference.



PERCENT OF TIME THAT ORDINATF IS EXCEEDED

Figure 5. Cumulative distributions of signal level for the time period indicated.



PERCENT OF TIME THAT ORDINATE IS EXCEEDED

Figure 6. Cumulative distributions of signal level for the time period indicated.

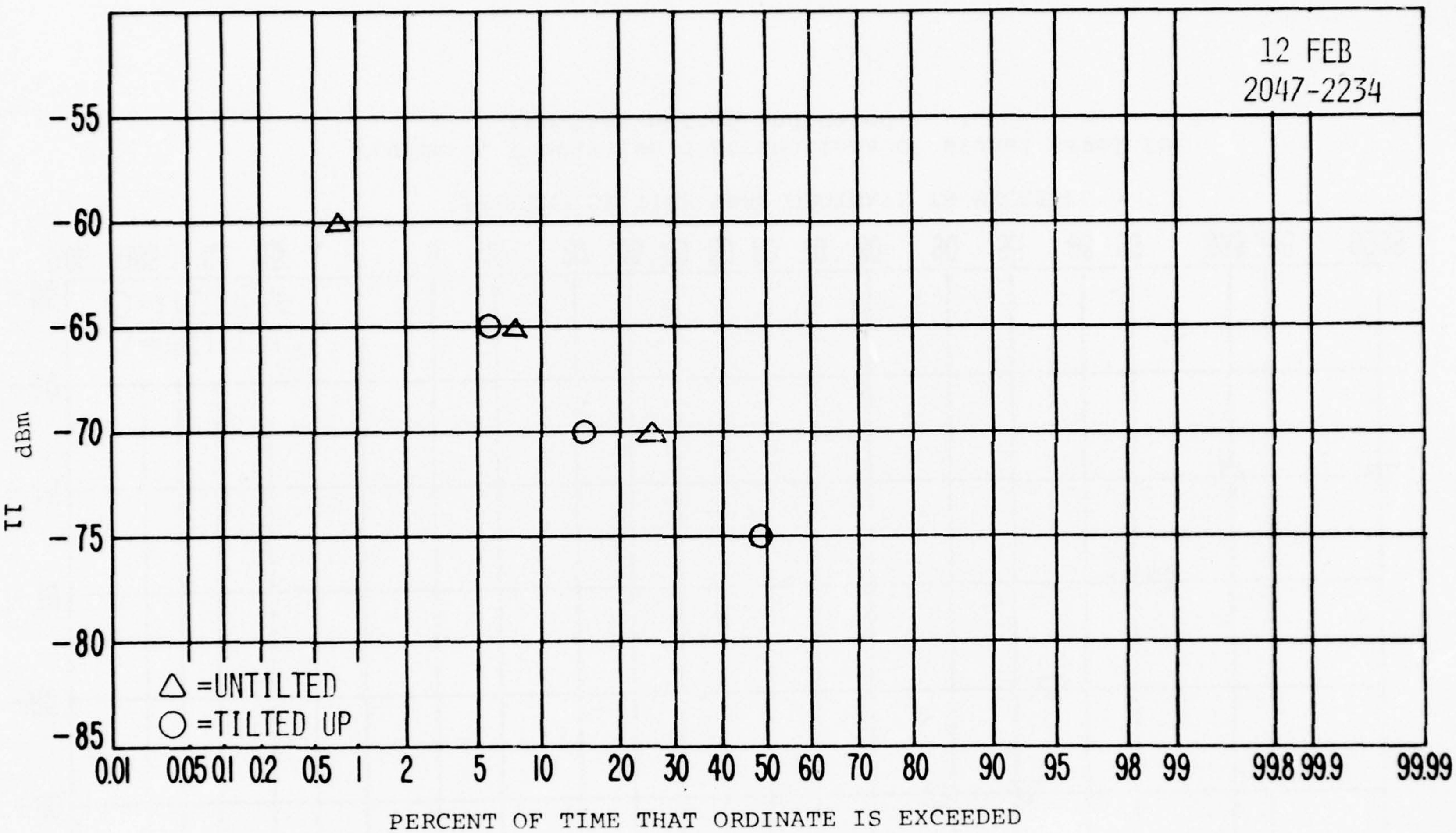


Figure 7. Cumulative distributions of signal level for the time period indicated.

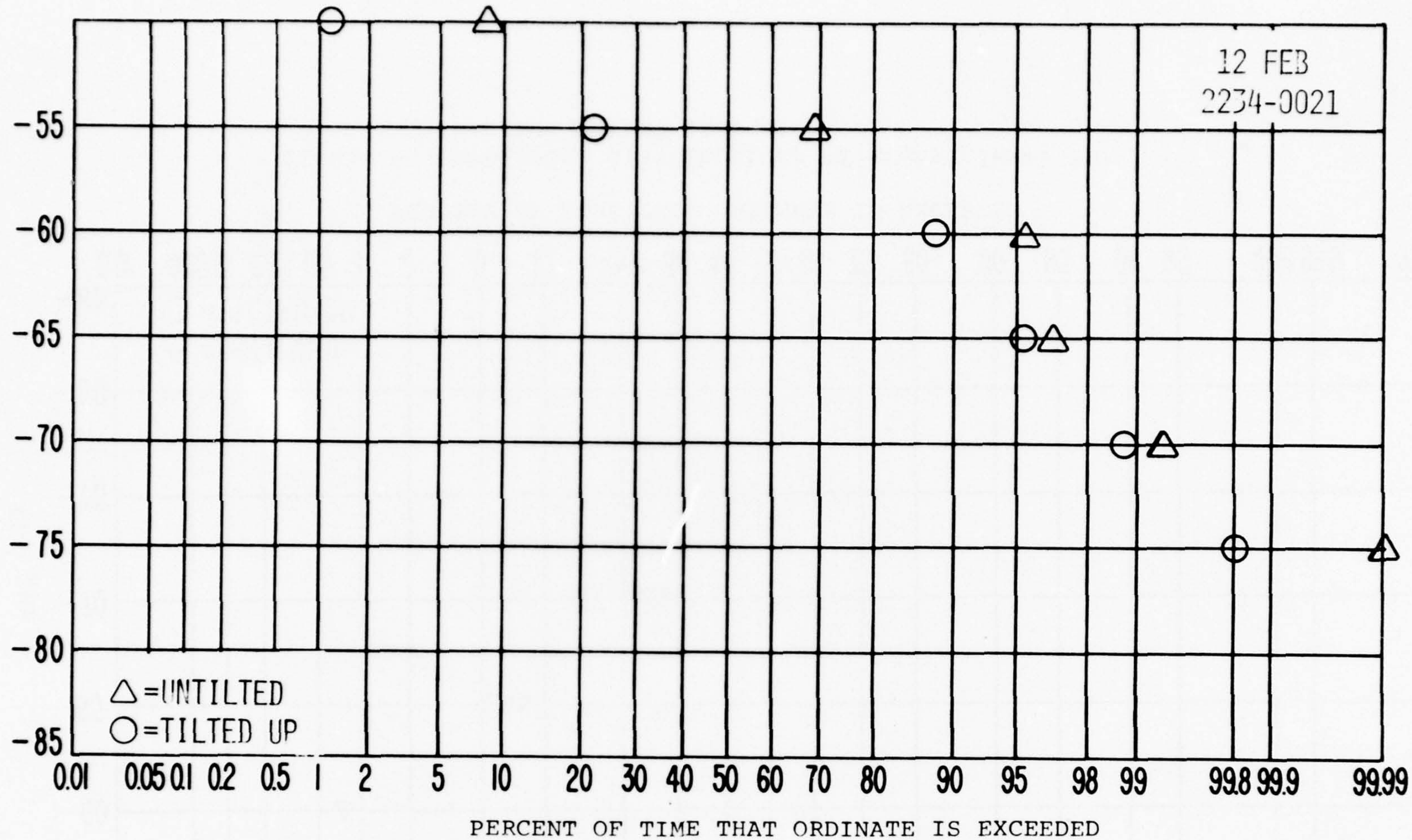


Figure 8. Cumulative distributions of signal level for the time period indicated.

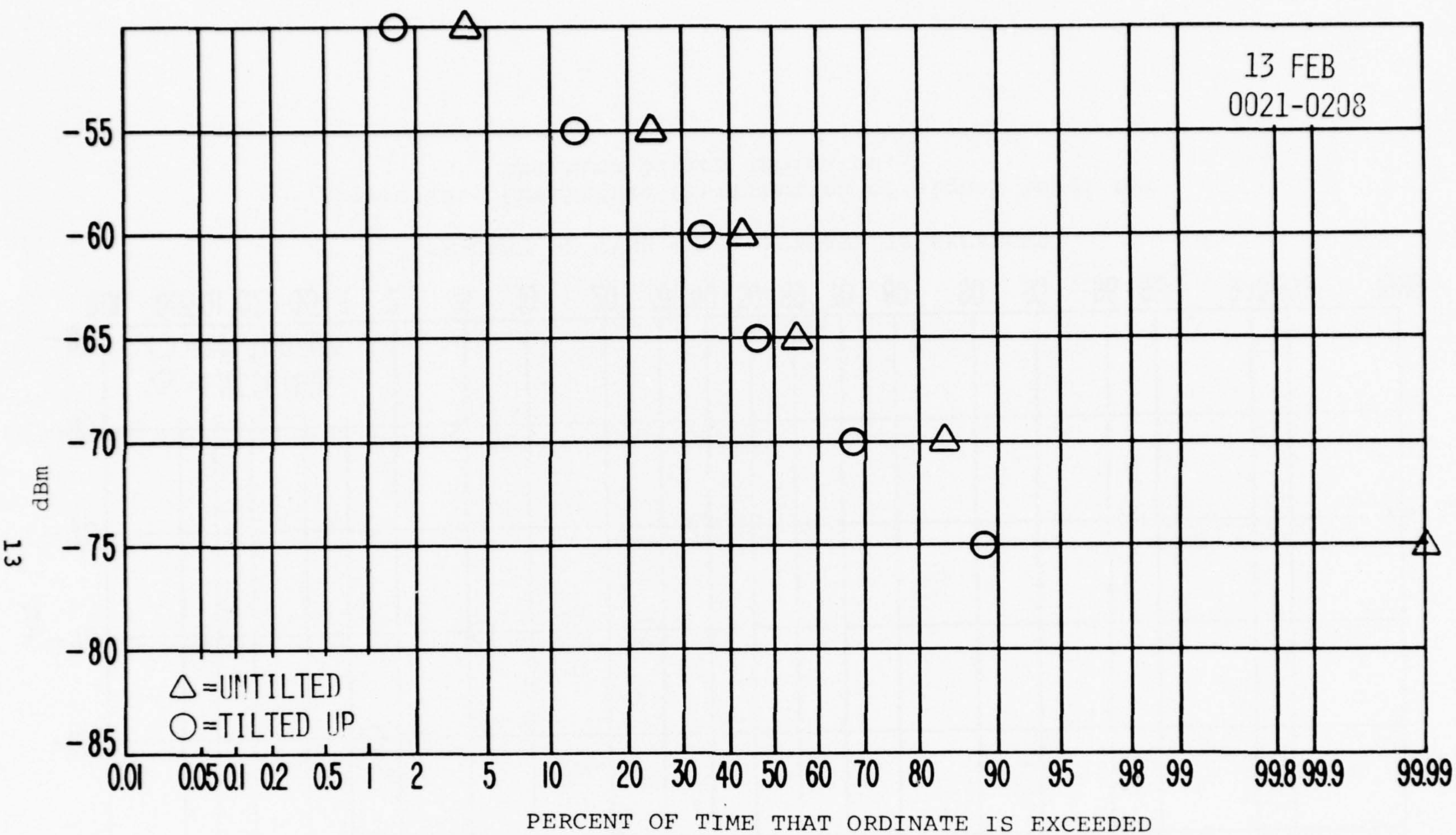


Figure 9. Cumulative distributions of signal level for the time period indicated.

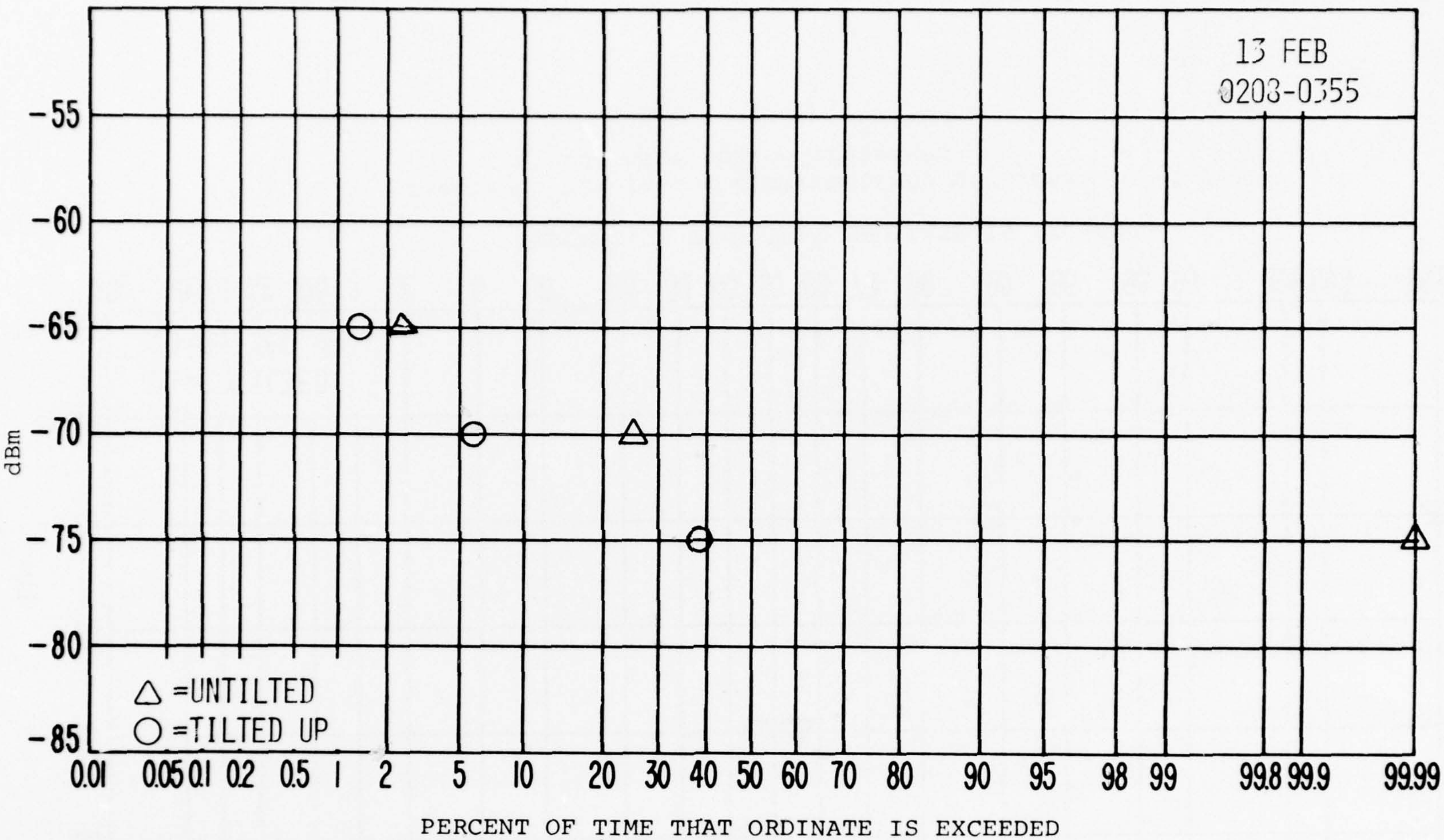


Figure 10. Cumulative distribution of signal level for the time period indicated.

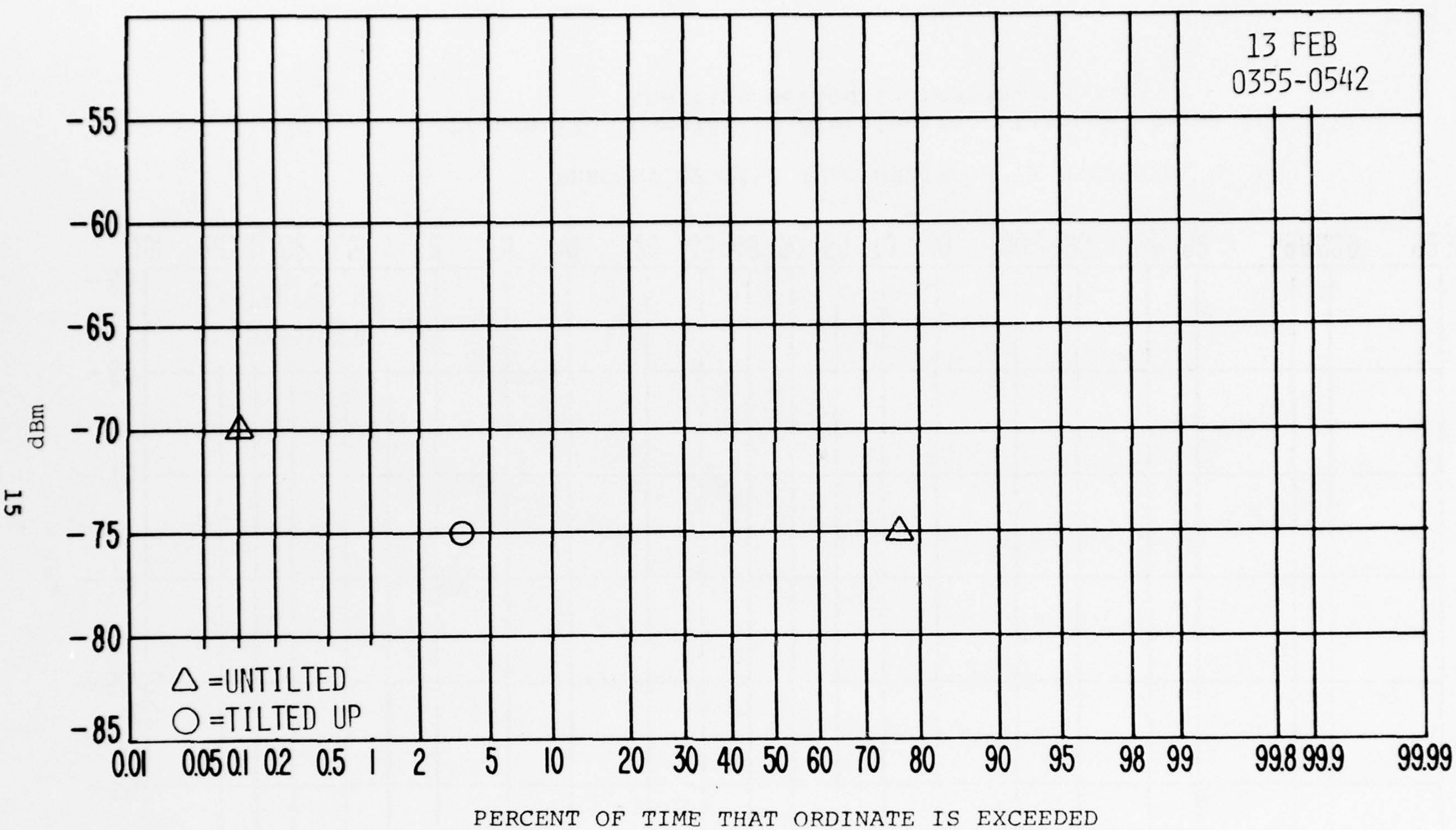


Figure 11. Cumulative distribution of signal level for the time period indicated.

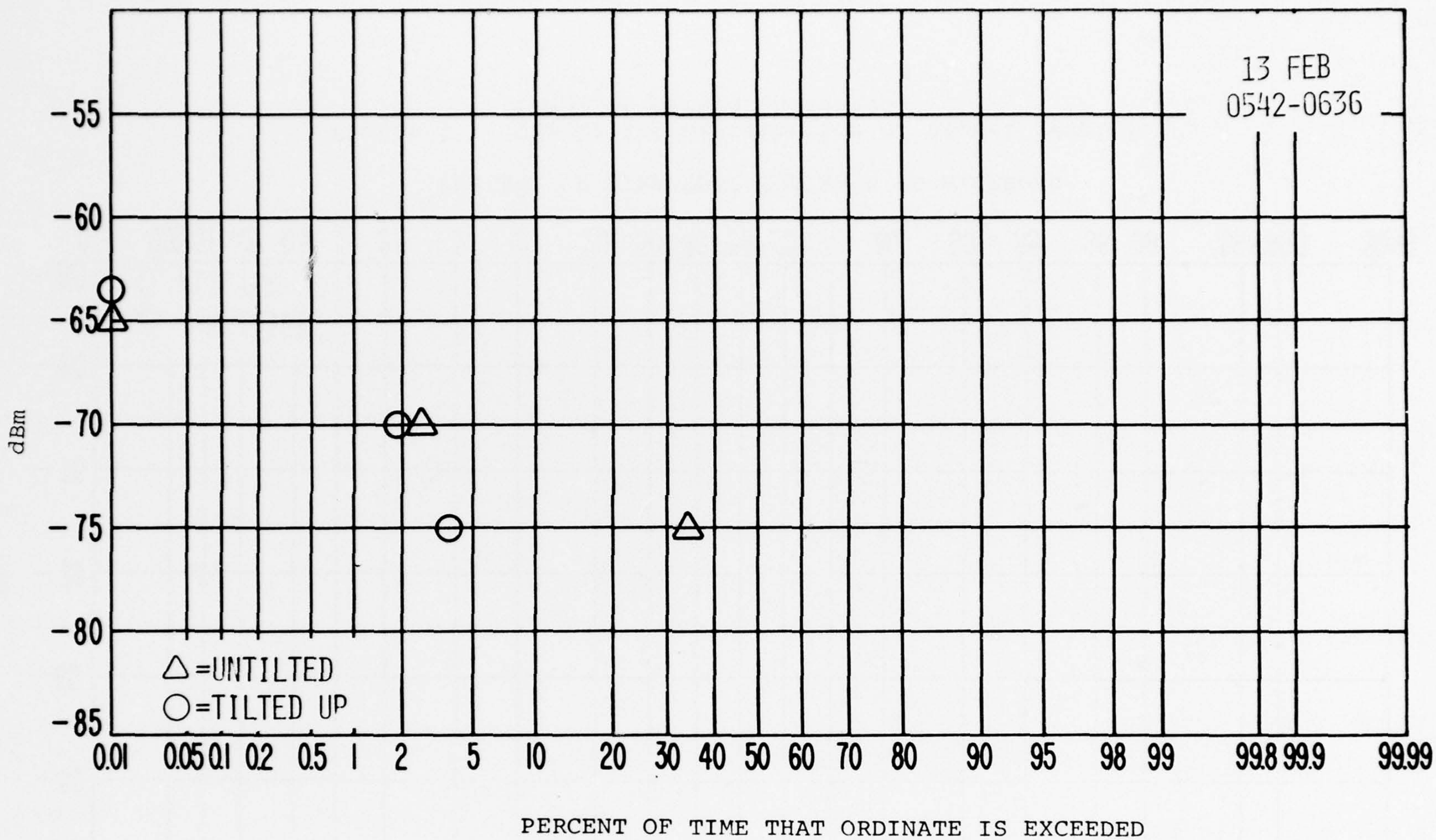


Figure 12. Cumulative distribution of signal level for the time period indicated.

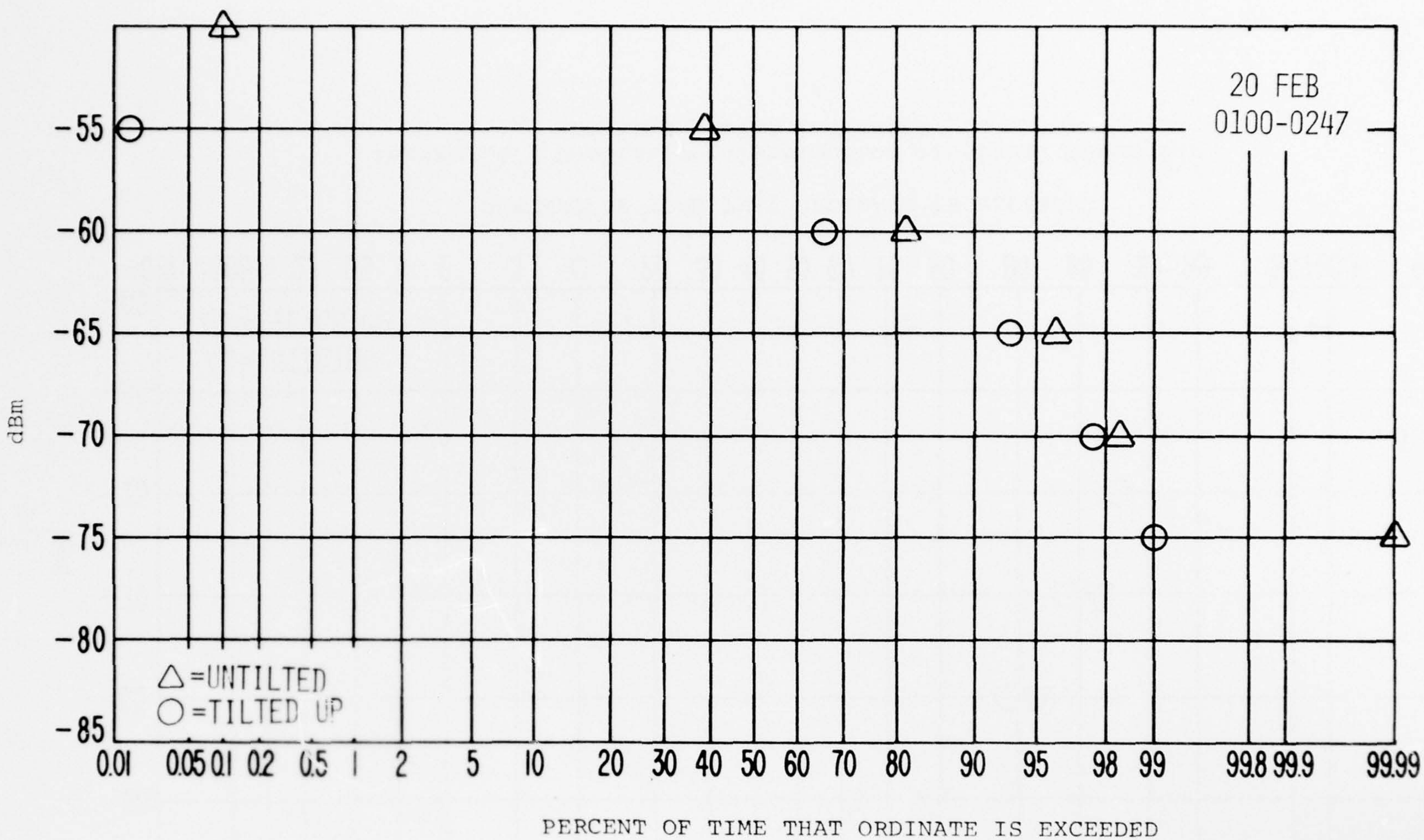


Figure 13. Cumulative distribution of signal level for the time period indicated.

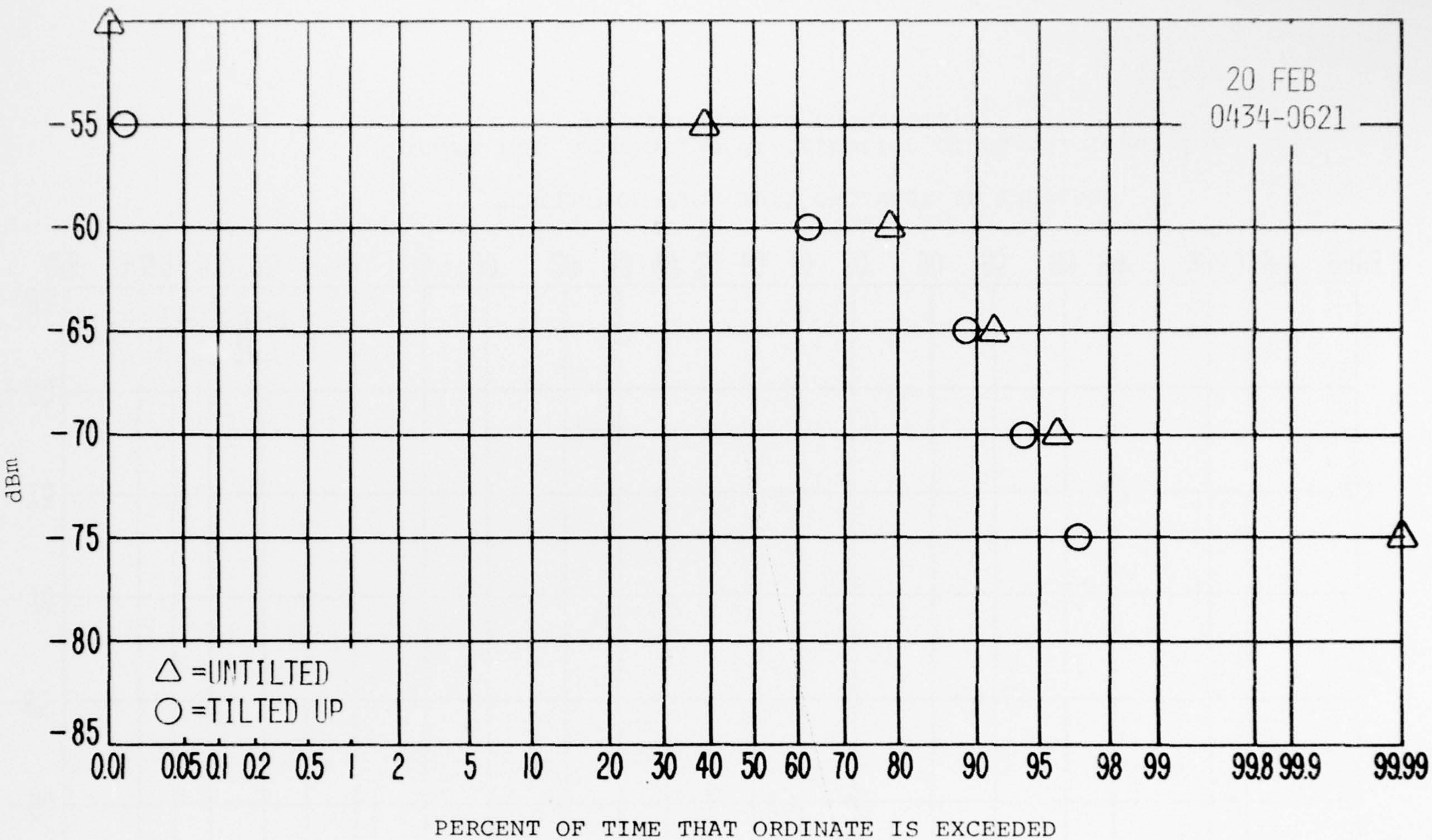


Figure 14. Cumulative distribution of signal level for the time period indicated.

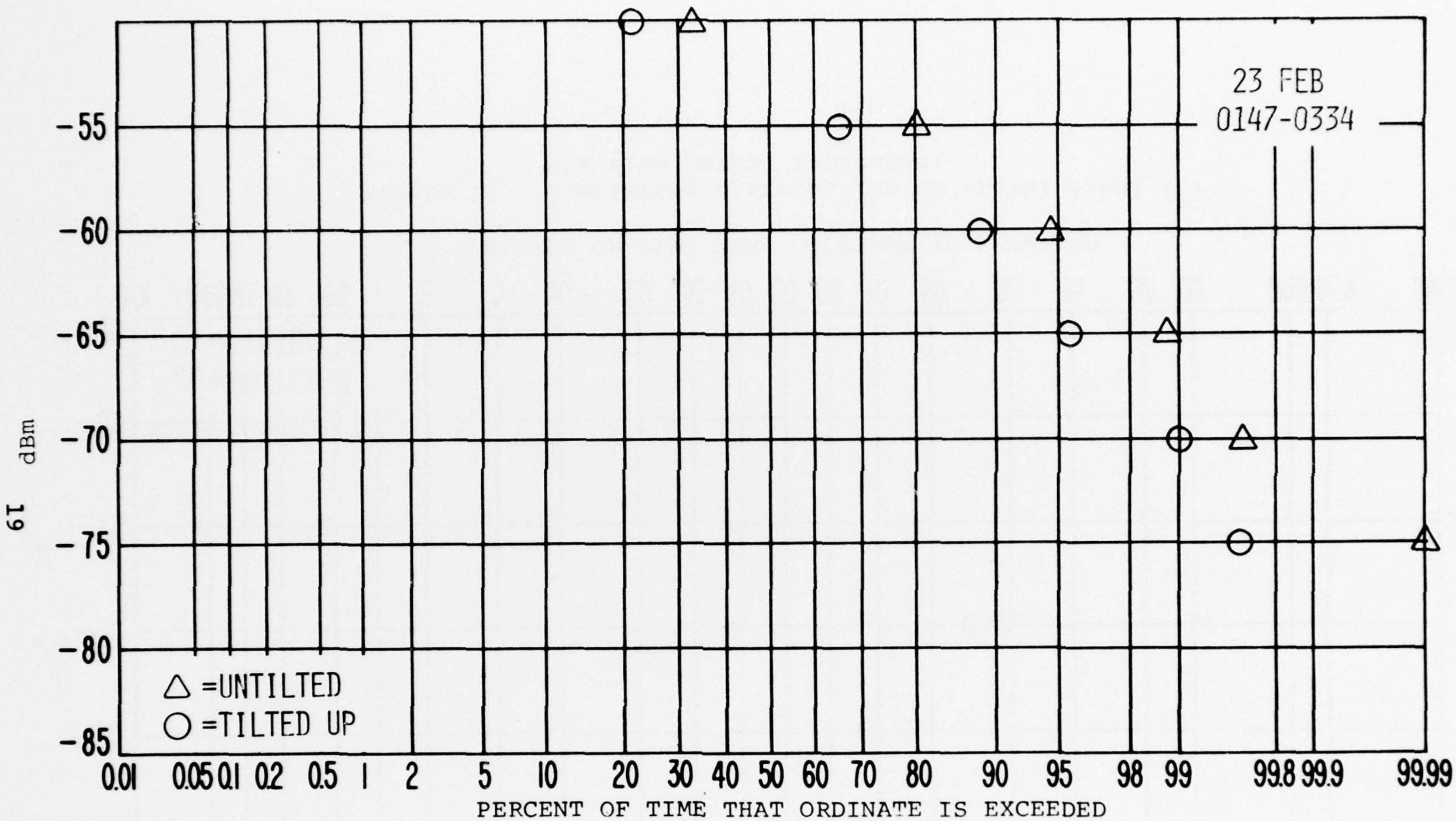


Figure 15. Cumulative distribution of signal level for the time period indicated.

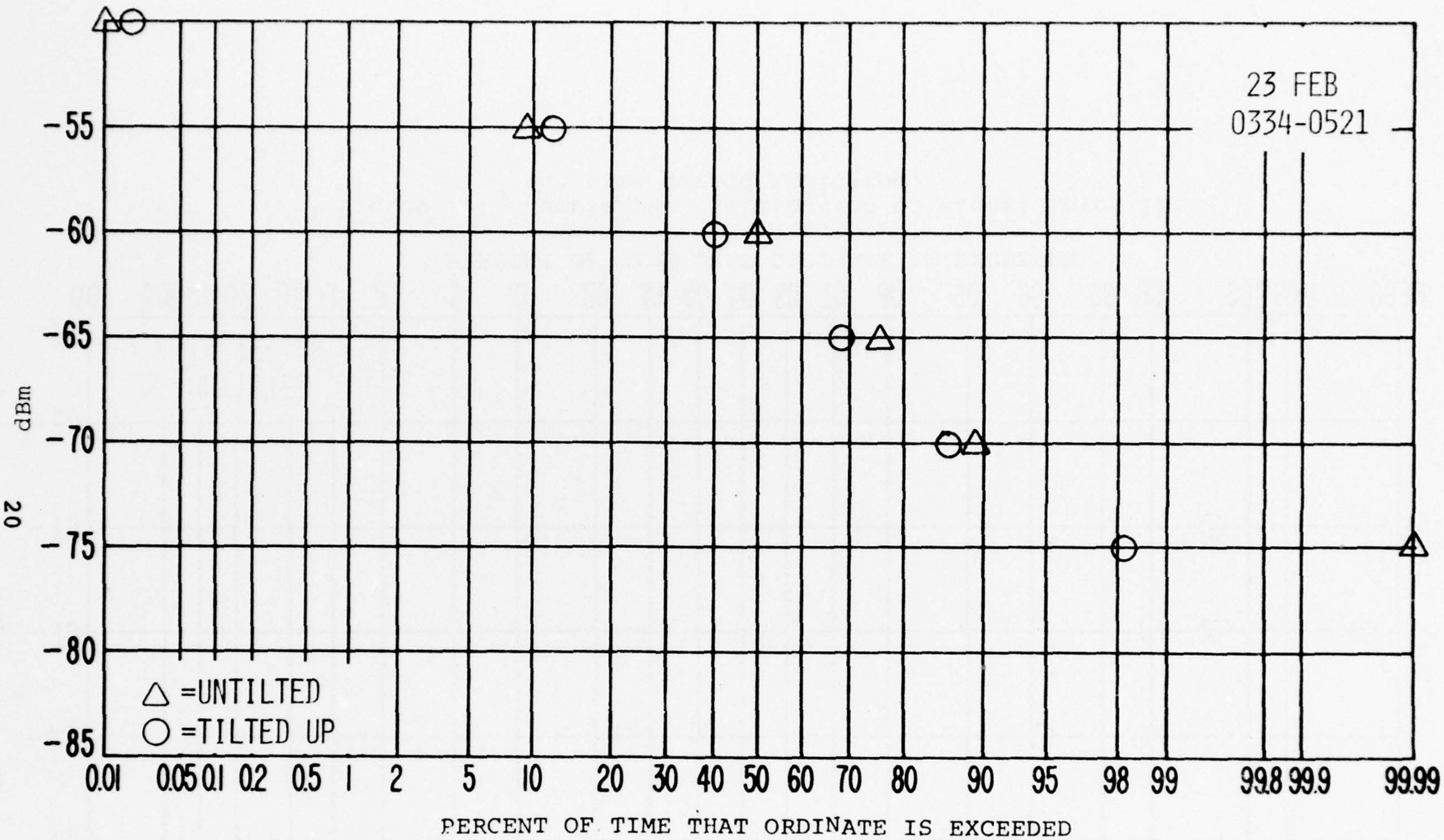


Figure 16. Cumulative distribution of signal level for the time period indicated.

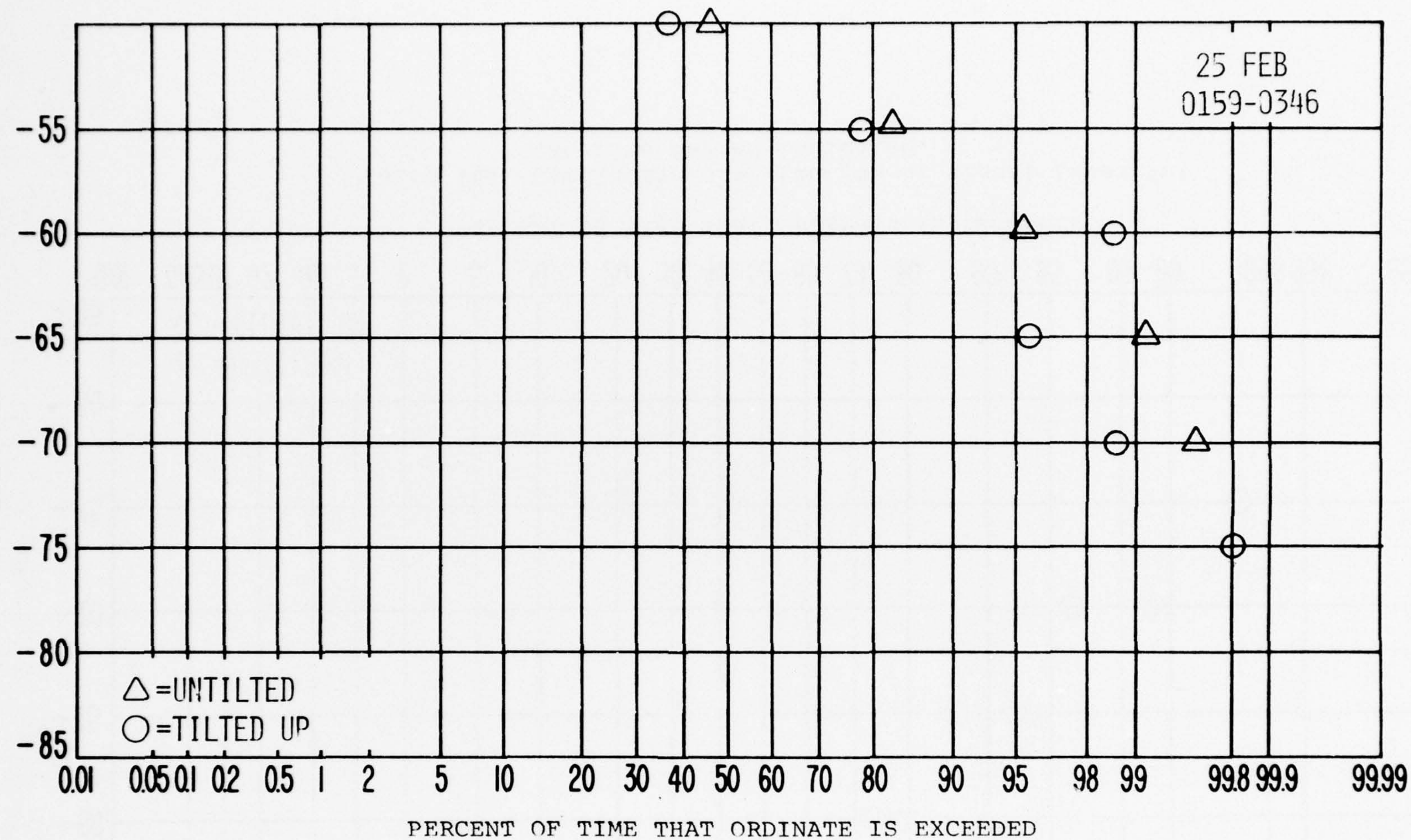


Figure 17. Cumulative distribution of signal level for the time period indicated.

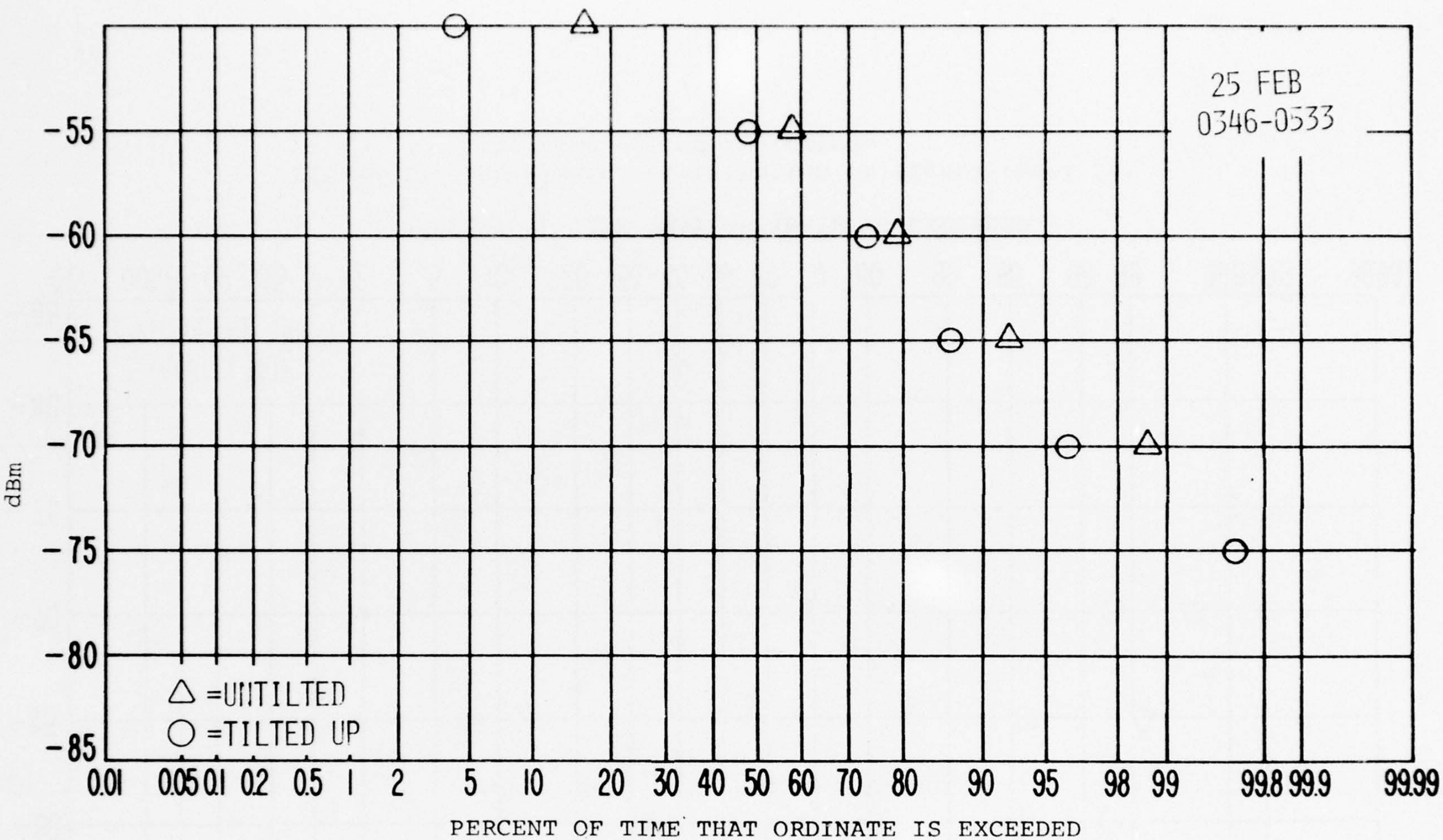


Figure 18. Cumulative distribution of signal level for the time period indicated.

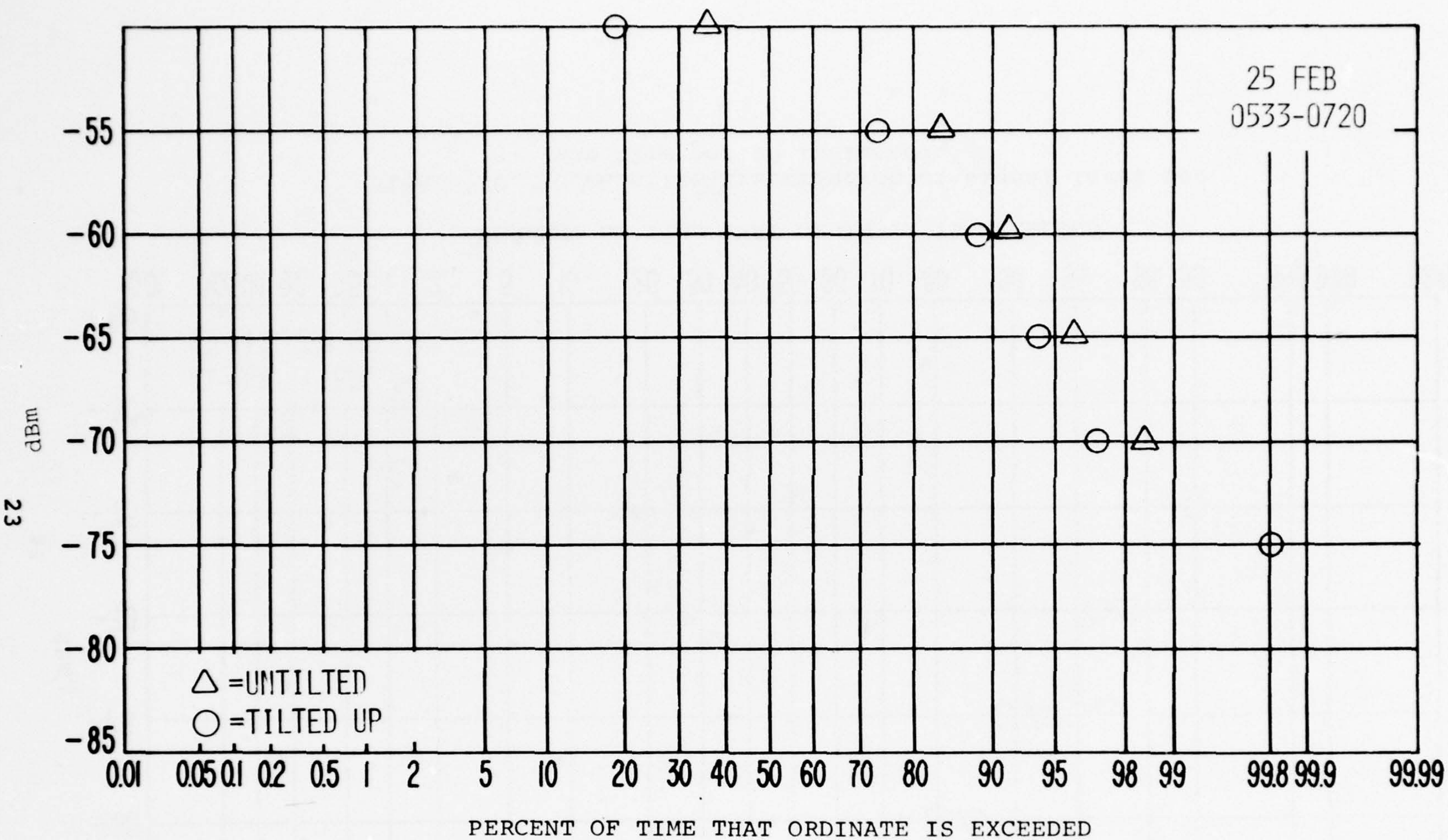


Figure 19. Cumulative distribution of signal level for the time period indicated.

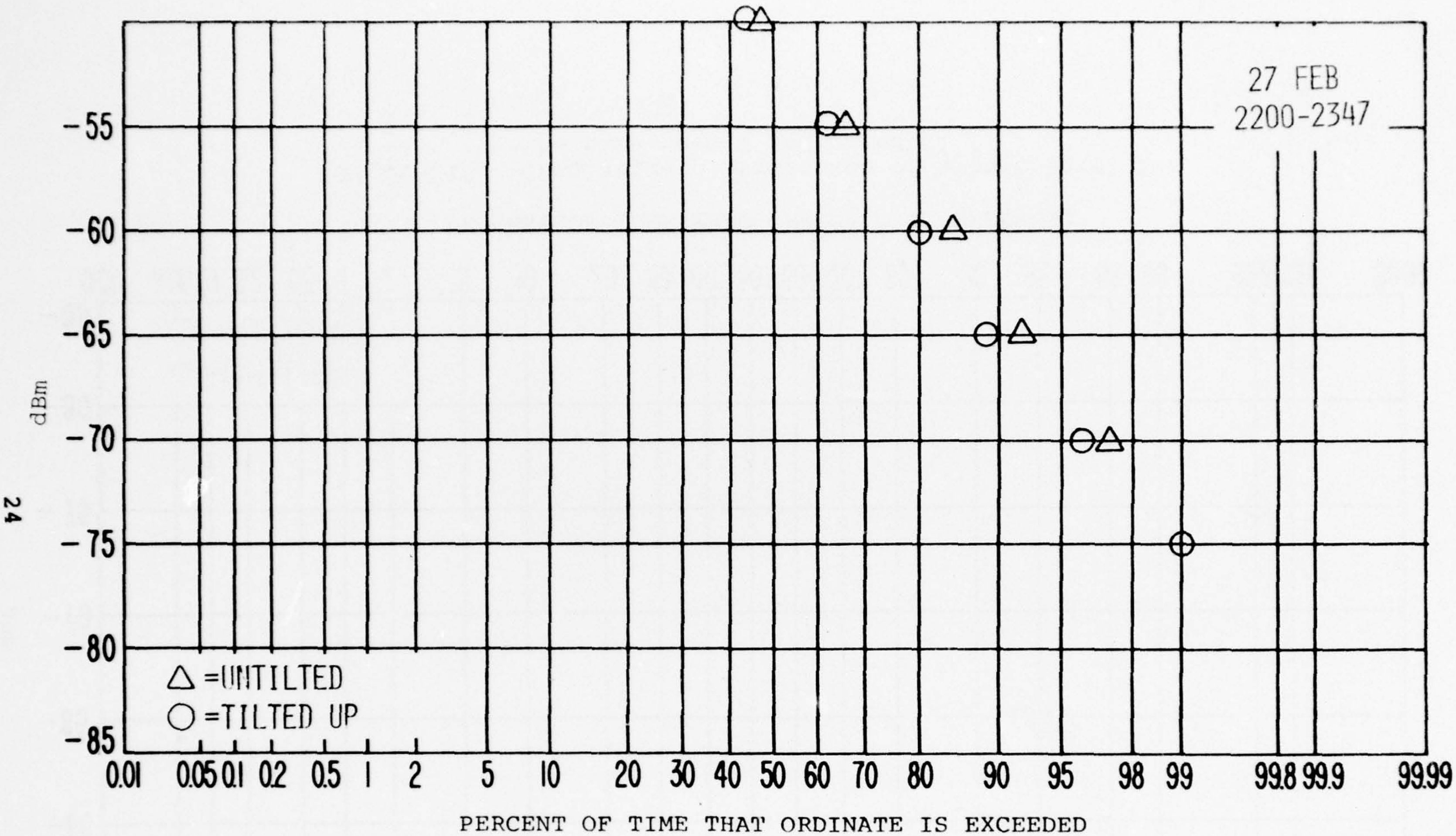


Figure 20. Cumulative distribution of signal level for the time period indicated.

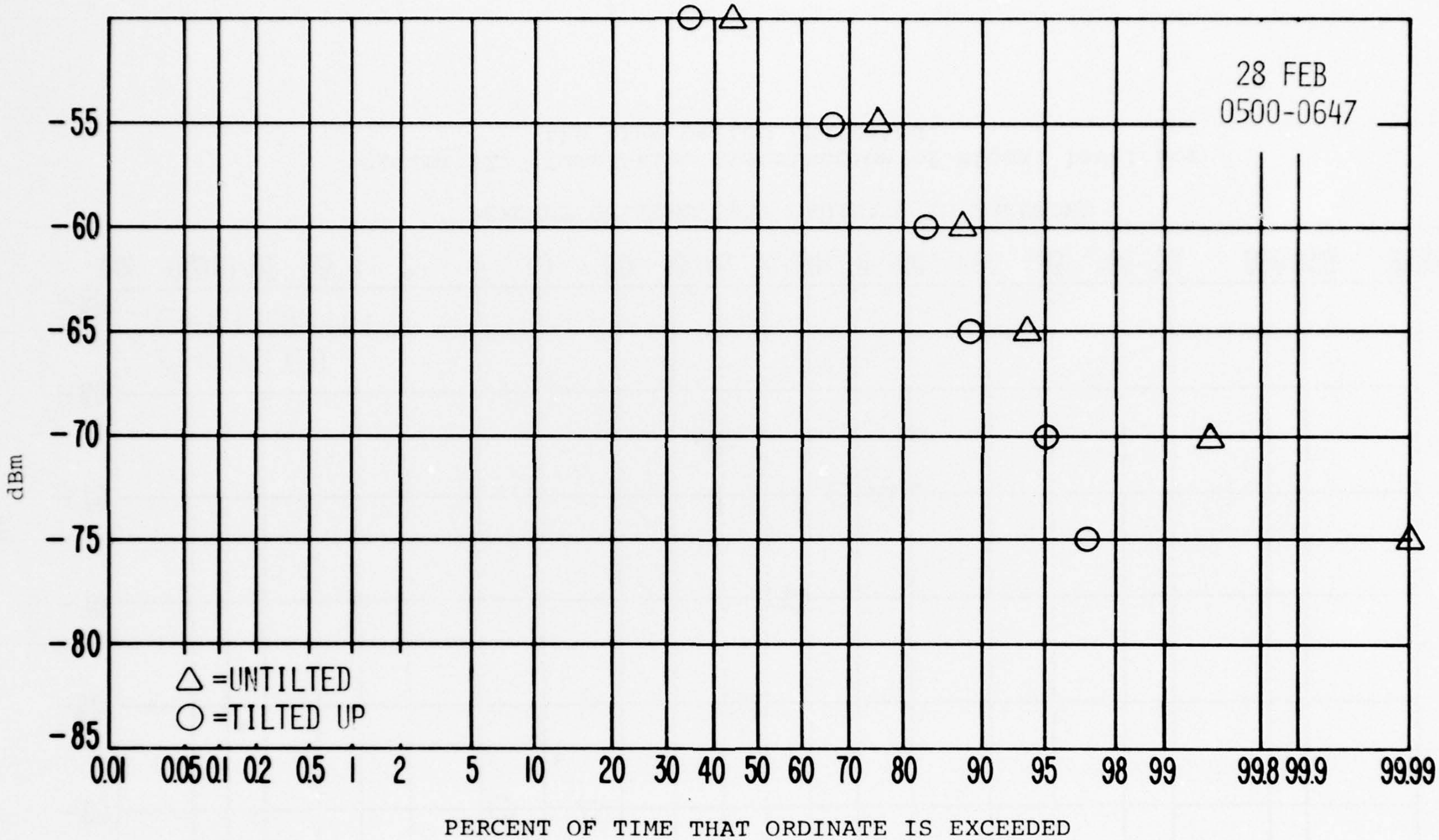


Figure 21. Cumulative distribution of signal level for the time period indicated.

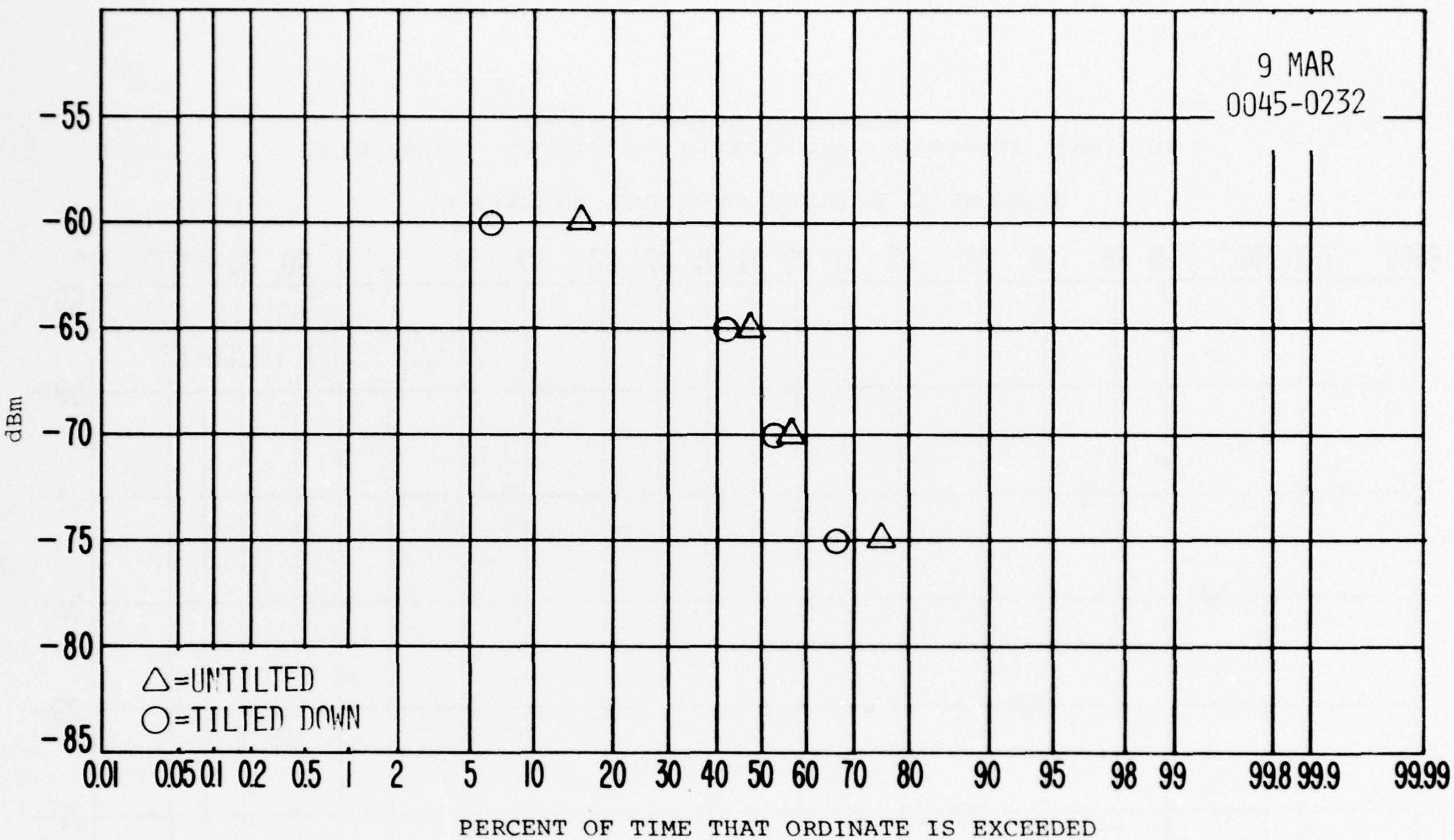


Figure 22. Cumulative distribution of signal level for the time period indicated.

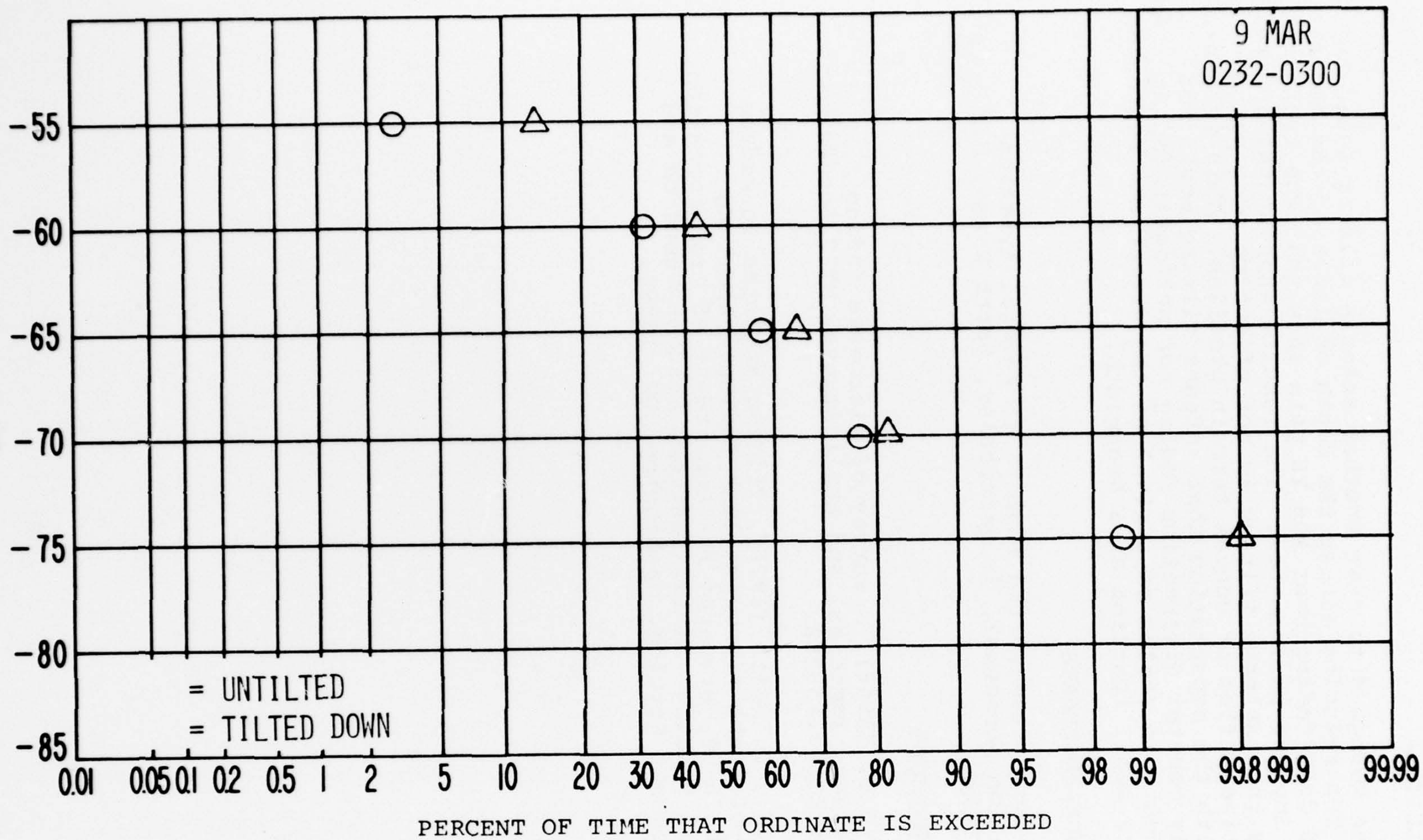


Figure 23. Cumulative distribution of signal level for the time period indicated.

VI. CONCLUSIONS

Experiments designed to test whether antenna tilting would be effective for reducing either the depth of fades or the amount of time of deep fading over the YH path show that the technique would not improve performance. The results support the general hypothesis that antenna tilting is not effective over paths with relatively flat or convex terrain profiles. This is consistent with the expectation that antenna tilting would not effectively counter diffraction fading nor multipath fading when the difference in angles of arrival of the direct and reflected paths are a small fraction of a beamwidth.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

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Hartman, W.J., D. Smith (1975), Tilting antennas to reduce light-of-sight microwave link fading, Report No. FAA-RD-75-38, prepared for Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, DC 20590.